

# **Executive Report**

**on**

**Basic Research on Self-Organized Quantum Dots  
and  
Their Potential in Solar Cells and Novel Devices Applications  
(Phase III)**

**Year 2005**

**by**

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14. ABSTRACT <p><b>Aim to achieve a minimum of 30 % conversion efficiency solar cells using Quantum Dot Molecule (QDM) structure QDM. Solar Cells are simpler to fabricate than tandem (Multijunction) solar cells. The QDM solar cells have very high efficiency (60 % in theoretical calculation) solar energy conversion. Achieve QDMs with high dot density (~1012 cm<sup>-2</sup>), good dot uniformity and dot ordering are needed in this solar cell structure. Achieved 25.9 % non-optimized conversion efficiency QDM solar cell which was reported at WCPEC-4 in Hawaii. Further experiments are needed in order to optimize the number of stacked QDMs, depth of stacking QDM layers, capping materials, anti-reflection coating, fine structure of grid contacts and other parameters which can make us achieve the 30% plus efficiency.</b></p>				
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## **Abstract**

This is the research output from our AOARD-supported work on basic investigation of self-assembled quantum dots and their potential applications during 2005. The research project is the third year of AOARD-support following the previous ones in 2003 and 2004. During the past year, 4 international journal publications on elongated nanostructure, quantum dot molecules and their applications were published. Another 2 papers were submitted to journal publications in local and international journals. There were 5 technical papers on quantum dot molecule solar cells and modified growth techniques presented at major international solar cell conferences i.e. 31<sup>st</sup> IEEE Photovoltaic Specialist Conference, (Orlando), 20<sup>th</sup> European Photovoltaic Solar Energy Conference and Exhibition (Barcelona) and 15<sup>th</sup> International Photovoltaic Science and Engineering (Shanghai) and at China Nano 2005 (Beijing) and 31<sup>st</sup> International Conference on Micro-and Nano-Engineering 2005 (Wien). Another 4 technical papers were also presented at local Conference of electrical engineering in Phuket. At the end of 2005, 5 presentation on different aspects of quantum dots and their applications were given at a Field-Wise Seminar on Nanoelectronics and Photonics supported by AUN/SEED-Net at Hanoi University of Technology.

All our journal and technical papers (18 in total) acknowledge financial supports from AOARD as well as Thailand Research Fund (TRF).

Research work on high efficiency quantum dot molecule solar cells will continue and will be presented in upcoming 4<sup>th</sup> World Conference on Photovoltaic Energy Conversion in 2006. Progress in quantum dot application in quantum computing is another exciting area of our research in 2006.

## **Introduction**

The zero-dimensional nature of quantum dots is of great interest for novel nanoelectronic devices. For example, its application in quantum dot laser results in lasers having record low threshold current, allowing the device to operate very efficiently. Single-electron transport in the form of quantum-dot transistor leads to extremely low power electronics with high-speed performance much needed in today technology such as fibre communication and portable telecommunication sets.

Energy and environment problems are also of critical importance for mankinds. The higher the energy consumption, the greater the amount of environmental damage giving rise to the needs for new energy solutions. The research team at SDRL started activities on solar cell in 1975 when the first oil crisis occurred. The team has extensive experience in solar cell development, from crystalline silicon, thin-film amorphous silicon, GaAs/GaAlAs heterostructure, to the more recent quantum structures, i.e. quantum wells and quantum dots. Our research focuses on quantum dots for solar cell applications. The zero-dimensionality of quantum dots is the motivation for the research. InAs quantum dots have good response at long wavelengths of solar spectrum. Hence, an integration of quantum dots in solar cell structure will give higher efficiency of solar energy conversion.

Applications of quantum dots with the best commercial potential is high-performance laser diode providing 1.3 and 1.55  $\mu\text{m}$  wavelengths for fibre communication. Quantum dots with appropriate dot size and uniformity are key to such device, yet there are various aspects of controlling growth parameters of quantum dots in MBE process not fully understood.

Self-alignment of quantum dots by different modified growth techniques are investigated. This would lead to some novel nanoelectronic devices, e.g. single electron devices, quantum dot set for quantum cellular automata.

## **Research Outputs**

In 2005, the research outputs are concentrated on Self-Assembled Quantum Dot Molecules (QDMs) and their potential applications. The research outcomes were published and presented in international and local journals and conferences as well as in regional seminar, 18 in total (see attached reprints and documents). Self-assembled lateral InAs quantum dot molecules are fabricated by our original MBE growth technique of thin-capping-and-regrowth process. This unique quantum nanostructure is reproducible and controllable by in-situ RHEED monitoring.

Self-assembled quantum dot molecules have higher dot density than as-grown quantum dots (one order of magnitude). Therefore, they have high potential applications in both laser and solar cell structures. By repeating multi-cycles of thin-capping-and-regrowth MBE process, high-density quantum dot molecules of more than  $10^{12} \text{ cm}^{-3}$  are obtained. This high density quantum dot molecules with multi-stacked structure is used in solar cell devices. This research work is an invited paper of the 15<sup>th</sup> International Conference Photovoltaic Science and Engineering in Shanghai.

Quantum dot molecules with an elongated nanostructure give also an interesting polarization-dependent-photoluminescence at room temperature due to their anisotropic nature. This gives a potential application for polarized photoemitters which is needed in many optical communication systems. This work is reported at the 31<sup>st</sup> International Conference on Micro- and Nano- Engineering (MNE 2005) in Wien.

Control of dot number per QDM is also possible by capping temperatures. At low capping temperature of 430°C, QDM with 4 satellite dots are realized and have a promising application for Quantum Dot Cellular Automata (QCA) which is a new approach for quantum computer having low power consumption and high speed processing due to single electron and Coulomb repulsion. However, the same growth technique is applied for the fabrication of Quantum Dot Pairs (QDP) which are also useful for quantum computing based on the idea of quantum bit (qubit) using spintronics in a single quantum dot.

In 2006, we will pursue the applications of multi-stacked high-density InAs quantum dot molecules in solar cell heterostructure of GaAlAs/GaAs aiming at high efficiency solar cells. Meanwhile, research activity on low dot density for basic study of single quantum dot is also interesting for future quantum computing.

## **Summary**

In 2005, our research work was presented in 6 international conferences, in one national conference and in one regional seminar with 4 journal publications with peer reviewed and with other 2 journal submissions. Work on multi-stacked high-density quantum dot molecule solar cells was an invited paper at the PVSEC-15. Research on high efficiency quantum dot molecule solar cells will conducted in 2006 as well as basic study of single quantum dot and quantum dot pairs for future quantum computing.

## **List of Conference Papers (6 International / 4 National)**

1. "Quantum Dot Molecules for Photovoltaic Cell Application", Suwaree Suraprapapich, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, 31st IEEE Photovoltaic Specialists Conf. (IEEE 31st PVSC), Orlando, Florida, U.S.A., 3-7 January, 2005.
2. "Multi-Stacked Lateral Quantum Dot Molecules for Photovoltaic Applications", Suwaree Suraprapapich, Teerasak Panyawanichkul, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona Spain, 6-10 June, 2005.
3. "Self-Assembled InAs Lateral Quantum Dot Molecules Growth on (001) GaAs by Thin-Capping-and-Regrowth MBE Technique", Suwaree Suraprapapich, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, China NANO 2005, Beijing, China, 9-11 June, 2005.
4. "Polarization-Dependent Emission from Self-Assembled InAs Lateral Quantum Dot Molecules", Suwaree Suraprapapich, Songphol Kanjanachuchai, Supachok Thainoi and Somsak Panyakeow, 31st International Conf. on Micro and Nano-Engineering 2005, (MNE 2005), Vienna, Austria, 19-22 September, 2005.
5. "Thin-Capping-and-Regrowth MBE Technique for Quantum Dots and Quantum Dot Molecules", Suwaree Suraprapapich, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, 23rd North America Molecular Beam Epitaxy (NAMBE) 2005, Santa Barbara, California, USA., 11-14 Semtember, 2005.
6. "Multi-Stacked High Density Quantum Dot Molecules as PV Active Layer", Suwaree Suraprapapich, Sirichai Ruangdet, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, 15th International Photovoltaic Science and Engineering Conf. (PVSEC-15), Shanghai, China, 10-15 October, 2005.
7. "Polarized Photoluminescence of InAs/GaAs Linearly Aligned Quantum Dots", Nan Thidar Chit Swe, Suwaree Suraprapapich, Supachok Thainoi, Pornchai Changmoang, Chanin Wissawinthanon and Somsak Panyakeow, the 28th Electrical Engineering Conf. (EECON-28), The Pearl Village Hotel, Phuket, Thailand, 20-21 October, 2005.

8. "Study on Polarized Photoluminescence of Multi-Stacked Lateral Quantum Dot Molecules Fabricated by Multi-Cycles of Thin-Capping-and-Regrowth MBE Technique", Naparat Siripitakchai, Suwaree Suraprapapich, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, the 28th Electrical Engineering Conf. (EECON-28), The Pearl Village Hotel, Phuket, Thailand, 20-21 October, 2005.
9. "Effects of InAs Quantum Dots on Electron Mobility in GaAs", Teerasak Panyawanichkul, Suwaree Suraprapapich, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, the 28th Electrical Engineering Conf. (EECON-28), The Pearl Village Hotel, Phuket, Thailand, 20-21 October, 2005.
10. "An Analysis of GaAlAs Bragg Reflectors in  $1.3 \mu\text{m}$  Range", Hassanet Sodabanlu, Poonyaseri Boonpeng and Somchai Ratanathammaphan, the 28th Electrical Engineering Conf. (EECON-28), The Pearl Village Hotel, Phuket, Thailand, 20-21 October, 2005.

### **List of Journal Publications (5 International / 1 National)**

1. "Self-Assembled Indium-Arsenide Elongated Nanostructure Grown by Molecular Beam Epitaxy", Suwaree Suraprapapich, Supachok Thainoi, Chanin Laliew (Wissawinthanon), Songphol Kanjanachuchai and Somsak Panyakeow, International Journal of Nanoscience, Vol. 4, No. 2, pp. 1-7, 2005.
2. "Ordered Quantum Dots Formation on Engineered Template by Molecular Beam Epitaxy", Suwaree Suraprapapich, Songphol Kanjanachuchai, Supachok Thainoi and Somsak Panyakeow, Microelectronics Engineering, Vol. 78-79, pp. 349-352, 2005.
3. "Self-Assembled Quantum Dot Molecules by Molecular-Beam Epitaxy", Suwaree Suraprapapich, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, Journal of Vacuum Science and Technology B. 23(3), May/Jun, 2005.
4. "Quantum Dot Molecules for Quantum Cellular Automata: Future Quantum Computer", Naparat Siripitakchai, Suwaree Suraprapapich, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, ECTI, Transactions on Electrical Eng., Electronics, and Communications, Vol. 3, No. 1, February, 2005.

5. "Regrowth of Self-Assembled InAs Quantum Dots on Nanohole- and Stripe Templates", Suwaree Suraprapapich, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, JM3 (Submitted to JM3, Nanopatterning Special Issue), 2005.
6. "Quantum Dot Molecules for Quantum Computing", Suwaree Suraprapapich, Supachok Thainoi, Songphol Kanjanachuchai and Somsak Panyakeow, KKU Engineering, Journal Khonkaen University Engineering Journal. (accepted and to be published in 2005)

### **List of Technical Papers for Regional Seminar**

1. "Self-Assembled Quantum Dot Molecules and their Potential Applications in Nanoelectronics and Photonics", Somsak Panyakeow, Field-Wise Seminar on Nanoelectronics and Photonics at Hanoi University of Technology, Vietnam, 14-15 November, 2005.
2. "Quantum Dots for Quantum Computing", Naparat Siripitakchai, Suwaree Suraprapapich and Somsak Panyakeow, Field-Wise Seminar on Nanoelectronics and Photonics at Hanoi University of Technology, Vietnam, 14-15 November, 2005.
3. "Quantum Dot Molecule Solar Cells", Songphol Kanjanachuchai and Somsak Panyakeow, Field-Wise Seminar on Nanoelectronics and Photonics at Hanoi University of Technology, Vietnam, 14-15 November, 2005
4. "Polarization Dependence of Photoluminescence of Quantum Dots and Their Related Nanostructure", Nan Thidar Chit Swe, Chanin Wissawinthon and Somsak Panyakeow, Field-Wise Seminar on Nanoelectronics and Photonics at Hanoi University of Technology, Vietnam, 14-15 November, 2005
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